STRESSTEL
ULTRASONIC TESTING EQUIPMENT

BOLT STRESS MEASUREMENT USING ULTRASONICS

This document presents a brief description of fastener elongation measurement using ultrasonics. For more details on ultrasonic testing in general, ULTRASONIC TESTING OF MATERIALS, by Josef and Herbert Krautkramer, 4th Edition 1990, (IBSN 0-387-51231-4), is highly recommended.

1. ULTRASONIC PROPERTIES

The BoltMike III measures the time of flight of a shock wave as it travels through a fastener. This type of shock wave is called a longitudinal wave. A shock wave is created when an electrical pulse is applied to a piezoelectric element inside the transducer. The frequency of the shock wave is controlled by the thickness of the piezoelectric element. The frequencies useful for fastener measurements range from 1 to 10 megahertz. This range of ultrasound will not travel through air. A dense liquid substance, usually glycerin or oil, must be used to couple the ultrasound from the transducer into the fastener.

When the ultrasonic wave encounters an abrupt change in density, such as the end of the fastener, most of the wave reflects. This reflection travels back through the length of the fastener, through the layer of couplant and back into the transducer. When the shock wave enters the piezoelectric element, a small electrical signal is produced. This signal is amplified by the BoltMike III and used to stop the timing counter.

Ultrasound travels in a fastener at a constant speed determined by many material factors, such as density, temperature and stress. The velocity may be found by dividing twice the physical length of the fastener by the transit time. It is important to realize that the sound velocity varies from sample to sample even when the sample materials composition is tightly controlled. Therefore, the ultrasonic reference length is not exactly the same as the physically measured length. Even if the length of a fastener is very tightly controlled, the ultrasonic length may vary by as much as one percent. For accurate measurements of elongation, the change in ultrasonic length can be used. This requires a before and after measurement of the ultrasonic length for each fastener.

The BoltMike III measures an ultrasonic reference length by measuring the time from the launching of the ultrasonic wave to the reception of the echo from the end of the fastener. This time is divided by 2 and then multiplied by the sound velocity to produce the length. In order to obtain the required resolution, multiple samples are averaged. Sufficient time must be allowed for the ultrasound to diminish before firing another pulse into the fastener to obtain a stable reading.

2. EFFECTS OF STRESS

When a fastener is placed under stress, its length changes. The greater the stress the greater the length change. In the elastic region, below the yield stress of the bolt, this relationship is linear and described by Hooke´s law. The modulus of elasticity is the constant describing the ratio of stress to strain for a given material.

The velocity of sound in a material is also effected by stress. As a fastener is stretched, velocity of ultrasound through the fastener decreases. This makes the fasteners ultrasonic length longer than the physical length change due to stress. A great deal of confusion surrounds this effect. If a reference length is recorded on a faster with no applied load, then a load is applied and a new reference length is taken, the difference between the two reference lengths is about three times the physical elongation of the fastener. In the BoltMike III, a constant known as the Stress Factor (K) compensates for the change in ultrasonic velocity due to stress.

It is important to note that in order to change the sound velocity; stress must be applied in the same direction as the travel of the ultrasound. Thus stress due to shear loading or torsional stress due to tightening does not effect the sound velocity along the length of the fastener.

3. EFFECTS OF TEMPERATURE

The temperature of a fastener effects its physical length and the velocity the ultrasound travels. As the temperature of a fastener increases, its ultrasonic length increases at a rate greater than the physical length changes. The BoltMike III temperature compensation corrects the ultrasonic length of a fastener to normalize it to 72 degrees Fahrenheit. Therefore, a fastener will always measure the same length at all temperatures if properly compensated. The thermal expansion of the fastener and ultrasonic velocity change with temperature are two separate effects. However, for the purpose of the BoltMike III they are combined into a single factor known as the Temperature Coefficient (Cp).

4. REQUIREMENTS OF ULTRASONIC MEASUREMENT

Not all fastener applications are suitable for measurement by ultrasonic methods. An understanding of the limitations will prevent frustration and erroneous results. Fastener applications where equal distribution of load is critical, typically find ultrasonic techniques indispensable. These applications include pipe flanges and head bolts, where gaskets must be compressed evenly for optimum performance.

Significant Stretch

Since ultrasonic technique measures the change in length of a fastener, a significant amount of stretch is required to produce accurate measurements. Applications where a fastener is clamping a very short grip length, such as a screw holding a piece of sheet metal, have large accuracy problems. Because the stress is applied over a very short effective length, little, if any, elongation of the fastener occurs. The amount of stretch is small compared to the error involved in removing and replacing the transducer.

Another difficult application is the measurement of very low loads. At low stress levels, below 10% of ultimate tensile stress, similarly low elongation takes place. The small errors in measurement associated with removing and replacing the transducer become very significant when trying to measure such a small amount of elongation.

Flat Ends for Transducer

In order to inject and receive ultrasound from a bolt, the bolt must have a flat surface for the transducer to contact. The opposite end of the bolt should also have a parallel surface to reflect the ultrasound back to the transducer, although the surface finish is not as important.

Both ends should be flat and at right angles to the bolt axis. Very rough or uneven reflective faces can produce errors. Problems with surfaces are indicated by poor signal quality on the waveform display of the BoltMike III.

Material Must Conduct Ultrasound

Most metals are excellent conductors of ultrasound. However, certain cast irons and many plastics absorb ultrasound and cannot be measured with the BoltMike III.

Surface Finish

A very flat, smooth surface is extremely important to proper coupling of the transducer. A common problem occurs when a small peak is left in the center of a bolt head after milling the fastener head flat on a lathe. This small bump prevents the transducer from achieving proper contact and greatly reduces the signal amplitude.

The ideal finish for the transducer coupling point is between 32 to 63 micro inches CLA (0.8 to 1.6 micro meter Ra).

5. METHODS OF TRANSDUCER PLACEMENT

Accuracy is increased when the transducer, after tightening, is placed in the same position used when measuring the reference length. Several methods are in use today.

The most common method is to use a magnetic transducer and center the transducer on the end of the bolt. On large diameter bolts, above an inch in diameter, the position that gives the greatest amplitude of return echo should be used. Sometimes after tightening, due to bending of the bolt, this position may move. The position of the transducer should be changed to the location on the bolt that provides the maximum return echo signal. This assures the optimum sound path is being used, both before and after tightening. In non-magnetic bolt materials, fixtures are sometimes used to hold the transducer in place. Note that the fit between the transducer and the head of the bolt is extremely critical, and some provision must be made in the fixture to allow the transducer to “float” finding its own best position contact.

Transducer Selection
Basic to the operation of the BoltMike III is the ultrasonic transducer. There are a variety of transducers available, and there is overlap in their applications. This can make choosing the “best” transducer for the job difficult. Transducers vary in center frequency, diameter, and damping. There is no “rule of thumb” for selection. For an “easy” fastener, a large variety of transducers will measure with great results. In the case of a difficult fastener, transducer selection becomes more critical. The best way to evaluate an application is to use the BoltMike III waveform display. Try making readings with an assortment of transducers and observe the waveform display and the stability of the reading. Pick a transducer that provides a large signal and stable, repeatable readings when removing and replacing the transducer.

Transducer Frequency
The frequency of a transducer refers to the resonant frequency of the piezoelectric crystal. This is determined by the thickness of the crystal material. A thin crystal has a higher resonant frequency than a thick crystal. The BoltMike III will work with transducers in the 1 to 15 megahertz range.

The frequency of the transducer effects the transmission of ultrasound in two different ways, beam width and absorption.

The beam width or directivity of the sound decreases as frequency increases. This means that a 10MHz/.25” transducer has a tighter beam than a 5Mhz/.25” transducer. It is desirable to have a closely focused beam since more energy reaches the end of the fastener and noise from reflections off the thread and shank areas is reduced.

However, as frequency increases, the absorption of the ultrasound by the material also increases. This is especially true of the granular material found in castings. The lower frequency ultrasound travels around small flaws or air bubbles in the material without reflecting.

Transducer Diameter
The diameter of the transducer effects the beam width and directivity of the ultrasound. Also, a larger diameter crystal is more efficient at transmitting sound. The larger the diameter of the crystal element the more directed the ultrasound becomes. It is desirable to have a closely focused beam since more energy reaches the end of the fastener and noise from reflections off the thread and shank areas is reduced.

Therefore, select the largest transducer diameter that will fit on the fastener. Transducers that have a magnet built in are significantly larger than the piezoelectric element size. For example, the outside diameter of the 5MHz/.25” non-magnetic transducer is 3/8 inch while the same transducer in a magnetic housing has an outside diameter of 3/4 inch.

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